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# An experimental study on optimum concentration of silver-water microfluid for enhancing heat transfer performance of a plate heat exchanger

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ABSTRACT

The present work investigates the effects of different concentrations of silver-water microfluid on the thermophysical properties, Brownian motion and heat transfer performance of a plate heat exchanger. For this purpose, an experimental system which included a CR14-45 COMER plate heat exchanger, five pt100 platinum resistance temperature sensors with temperature control system, two rotameters for flow rate indication and control, an insulated reservoir tank with two immersed heaters in it and a stainless steel centrifugal pump for circulating fluid was prepared. In the next step, silver microparticles were synthesized from $AgNO_3$ and then 8 L of silver-water microfluid was prepared with different concentrations in the range of 0–0.125 wt% and their thermal conductivity, heat capacity and temperature difference rate were experimentally gauged. The results indicated that all the concentrations of silver-water microfluid (in the range of 0–0.125 wt%) enhance thermal conductivity and heat transfer rate in comparison with base fluid (pure water). However, there is an optimum concentration for microfluid (0.03 wt%) in which the rate of heat transfer reaches its maximum value. In this case, the heat transfer rate of microfluid is 9% higher than the base fluid. At high microparticles concentrations, due to coagulation effect, some of the silver particles quickly stick together and build deposits on the surface of the plate heat exchanger. Consequently, the concentration of the particles in the microfluid decreases and the enhancement of thermal conductivity (1.25% for 0.125 wt%) lowers in comparison with the optimum state. Furthermore, at concentrations beyond the optimum, the slope of temperature difference rate in microfluid is negative and, therefore, the Brownian motion and particles movement diminish and the silver particles tend to sediment. Microparticles deposited on the plate heat exchanger surface contribute to additional heat transfer resistance and decrease the heat transfer coefficients in comparison with the optimum state.



## 1. Introduction

There is now, more than ever, a growing demand for compact heat exchangers capable of transferring heat at low approach temperatures to achieve greater temperature crossing, which saves energy [1]. Plate heat exchangers, as a major kind of compact heat exchangers, have found widespread applications in the chemical and food sectors, which is due to their compactness, flexibility, their being easy to maintain and clean and their high thermal efficiency [2–4]. However, traditional heat transfer media (*e.g.* water, glycol, oil, etc.) cannot create the high intensity of heat transfer in plate heat exchangers [5,6]. It is well known that adding a certain amount of metals into liquids may enhance their thermal properties [7]. As high thermal conductivity materials, metal nanoparticles are widely used [8,9]. Novel metal nanoparticles have continued to arise in the recent years and the experiments using metal nanoparticles as thermal conductivity enhancing additives have quickly developed [10–12]. Many researches have widely investigated the thermal conductivity [13–16], viscosity [17–20] and unsteady characteristics of plate heat exchangers [21–26] in the presence of nanofluids. Ray et al. [27] presented experimental and theoretical analyses, which showed that the use of nanofluids instead of the conventional fluids can reduce the pumping power requirement and the size of the heat exchanger while achieving the same amount of heat transfer. They found out that a 0.5% $Al_2O_3$ nanofluid can reduce pumping power by 5.65% or reduce the surface area of the heat exchanger by 2%.

Mare et al. [28] compared the effects of two nanofluids on two competitor phenomena, *i.e.* the heat transfer enhancement

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and pumping power losses, in the performance of a plate heat exchanger at low temperatures. The two types of commercial nanofluids used were alumina ($Al_2O_3$) dispersed in water and aqueous suspensions of nanotubes of carbons (CNTs). Their results showed that in the laminar mode, the convective heat transfer coefficient improved about 42% and 50% for $Al_2O_3$ and CNTs, respectively, compared to that of pure water in the same Reynolds number.

Tiwari et al. [29] investigated the heat transfer performance and pressure drop characteristics of various nanofluids including $CeO_2$, $Al_2O_3$, $TiO_2$ and $SiO_2$ in plate heat exchanger (PHE). The experiments were done for a wide range of nanoparticle volume concentrations and coolant flow rates. For $CeO_2$-water, $Al_2O_3$-water, $TiO_2$-water and $SiO_2$-water nanofluids, the maximum heat transfer coefficient enhancements at the optimum volume concentration are about 35.9%, 26.3%, 24.1%, and 13.9%, respectively. The results revealed that $CeO_2$-water nanofluid has the highest performance index ratio in comparison with other nanofluids for the tested operating conditions. Furthermore, the requirement of $CeO_2$ nanoparticles is lower for the optimum operation, which leads to reduction in cost as well as in the problems related to sedimentation and agglomeration.

In another work, Tiwari et al. [30] investigated the convective heat transfer performance and pressure drop characteristics of a $CeO_2$-water nanofluid flowing in a PHE. Their experimental results indicated that the convective heat transfer coefficient increases with increase in volume flow rate of the heating and coolant fluids and nanofluid temperature drop. The augmentation of the overall heat transfer coefficient was found to be about 18.2%, 27.9%, 22.0%, 20.3%, 18.9%, 17.2% and 13.0% for 0.5, 0.75, 1.0, 1.25, 1.5, 2.0 and 3.0 vol.%, respectively.

The performance of a typical 4% CuO-water nanofluid used as a coolant in a typical commercial herringbone-type PHE was experimentally studied and compared to the performance of the base fluid (water) by Pantzali et al. [31]. All the thermophysical properties were measured systematically. They found out that the type of flow (laminar or turbulent) inside the heat exchanging equipment plays an important role in the effectiveness of a nanofluid. When the heat exchanging equipment operates under conditions that promote turbulence, the use of nanofluids is beneficial if the increase in their thermal conductivity is accompanied by a marginal increase in viscosity, which seems very difficult to be achieved. Therefore, the nanofluid properties should be defined carefully so its efficacy can be evaluated in a specific heat exchanger. Taghizadeh et al. [32] studied the convective heat transfer of multi walled carbon nanotubes (MWCNTs)-water nanofluid with different concentrations under the laminar and turbulent flow modes in a corrugated PHE. Their experiments revealed that the enhancement in the flow rate leads to dramatic enhancement of heat transfer coefficient in higher Peclet numbers. They reported that if the PHE operates under turbulent conditions, it shows a better heat transfer performance using nanofluid as hot fluid.

Silver nanoparticles are among the most well-known metal nanoparticles used in many fields such as textile engineering, electronic and optic applications and most importantly in the medical field as a bactericide and as a therapeutic agent [33–35]. They also have high thermal conductivity (429 W/m.K at 300 K) and therefore are expected to have good heat transfer properties ideally suitable for thermal applications such as in PHEs. However, in such practical applications, it is very important to reduce the costs, and silver nanoparticles high prices limit their application in PHEs. Furthermore, in practical applications, the raw materials need to get prepared through a simple and economical process and we know that nanoparticles preparation process is complex and costly. Also, new research has shown that exposure to nanoparticles can have a serious impact on health [36–42]. Microparticles have the same characteristics of nanoparticles with lower grades. However, they are produced at significantly lower costs in comparison with nanoparticles and consequently can be useful for practical applications such as enhancing characteristics of PHEs. Therefore, in this paper, a simple and feasible method is proposed for generating silver microparticles. The thermal characteristics of the silver-water microfluid at different concentrations are determined and the optimum concentration of the microfluid for use in a PHE is obtained.

## 2. Materials and methods

### 2.1. Chemicals

Silver nitrate ($AgNO_3$, 99%) and Sodium chloride (NaCl, 99.5%), were of analytical grade and were purchased from Merck/Germany. All glassware was washed in a mixture of distilled water and non-ionic detergent, rinsed with distilled water and ethanol for many times to get rid of any remnants of non-ionic detergent and dried prior to use.

### 2.2. Preparation of metallic silver and silver-water microfluid

In the first step, 15 gr of $AgNO_3$ was dissolved in 10 mL of distilled $H_2O$. Then 67 mL of NaCl saturated solution (360 g/L) was added dropwise to the $AgNO_3$ solution. At this stage, the white AgCl precipitate was observed [43]. Sliver chloride decomposes in the presence of light as stated by the following reaction equation called photo decomposition:

$$AgCI\ (s) \rightarrow Ag\ (s) + 1/2\ CI\ (g) \quad (1)$$

On AgCl(s) irradiation, electrons are excited from the valence to the conduction band. In the first step, a portion of metal ions in a solution reduced by formed electrons. The atoms thus produced act as nucleation centers and catalyze the reduction of the remaining metal ions present in the bulk solution [44,45]. After several minutes, the solution turned dark and metallic silvers were formed (Fig. 1).

Finally, the solution containing metallic silvers was diluted with distilled water to have silver-water microfluid with different concentrations (0–0.125 wt%).

As shown in Fig. 2, atomic force microscopy (AFM) was used for characterization of synthesized. The average size of silver microparticles was 0.153 and 0.613 µm for the most diluted silver-water solution (0.02 wt%) and optimum concentration (0.03 wt%), respectively. It can be seen that, in the most diluted silver-water solution, the size of silver particles was between the nano- and micro- scales. However, at the optimum concentration, the silver particles size was on the microscale. It is clear that, at higher concentrations than the optimum concentration, silver particles cling together and the particle size increases. Therefore, we use the term "microfluid".

### 2.3. Experimental set up and procedure

To investigate the heat transfer performance of silver-water microfluid, an experimental system shown schematically in Fig. 3 was designed and set up. The system consisted of a brazed plate heat exchanger (PHE) manufactured by COMER company (model CR14-45). The heat exchanger has 15 plates and the material used in plates is stainless steel 316(L). There is a nominal gap of 2.5 mm between any two plates. Fig. 4 shows the plate heat exchanger and the specification of the heat exchanger is presented in Table 1.

Hot and cold fluids flowed through the heat exchanger in opposite directions and, exchanging heat with each other, exited heat exchanger. Also, to minimize the heat loss from the plate heat exchanger, it had been covered by a layer of rock wool. Microfluid, as